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(54) Radio communications link with diversity

(57) A base station 10 has two transmitting antennas 20, 22 which both transmit the same signal to a mobile station 12, the signal via antenna 22 being delayed by a time delay unit 24 to ensure de-correlation between the transmitted signals. It is unlikely that multi-path fading will occur simultaneously in both signal paths to the single antenna 24 of the mobile station wherein an equaliser 26, such as a Viterbi equaliser, decodes the originally transmitted signal from the two superimposed signals received by antenna 24. Diversity is obtained without the need for two antennas at the mobile station where space limitations would probably prevent this. The base station 10 receives the signal transmitted from the single antenna 24 at the mobile station 12 over two signal paths respectively directed to the two antennas of the base station. The signals received are de-correlated by a time delay 38 connected to one of these antennas and summed, summed 36 and passed to an equaliser 40 for decoding. A repeater station may similarly include time delays (76), (82), (Figs 7, 8), to give de-correlation between the signals it retransmits and the corresponding signals directly transmitted by the base and mobile sections.

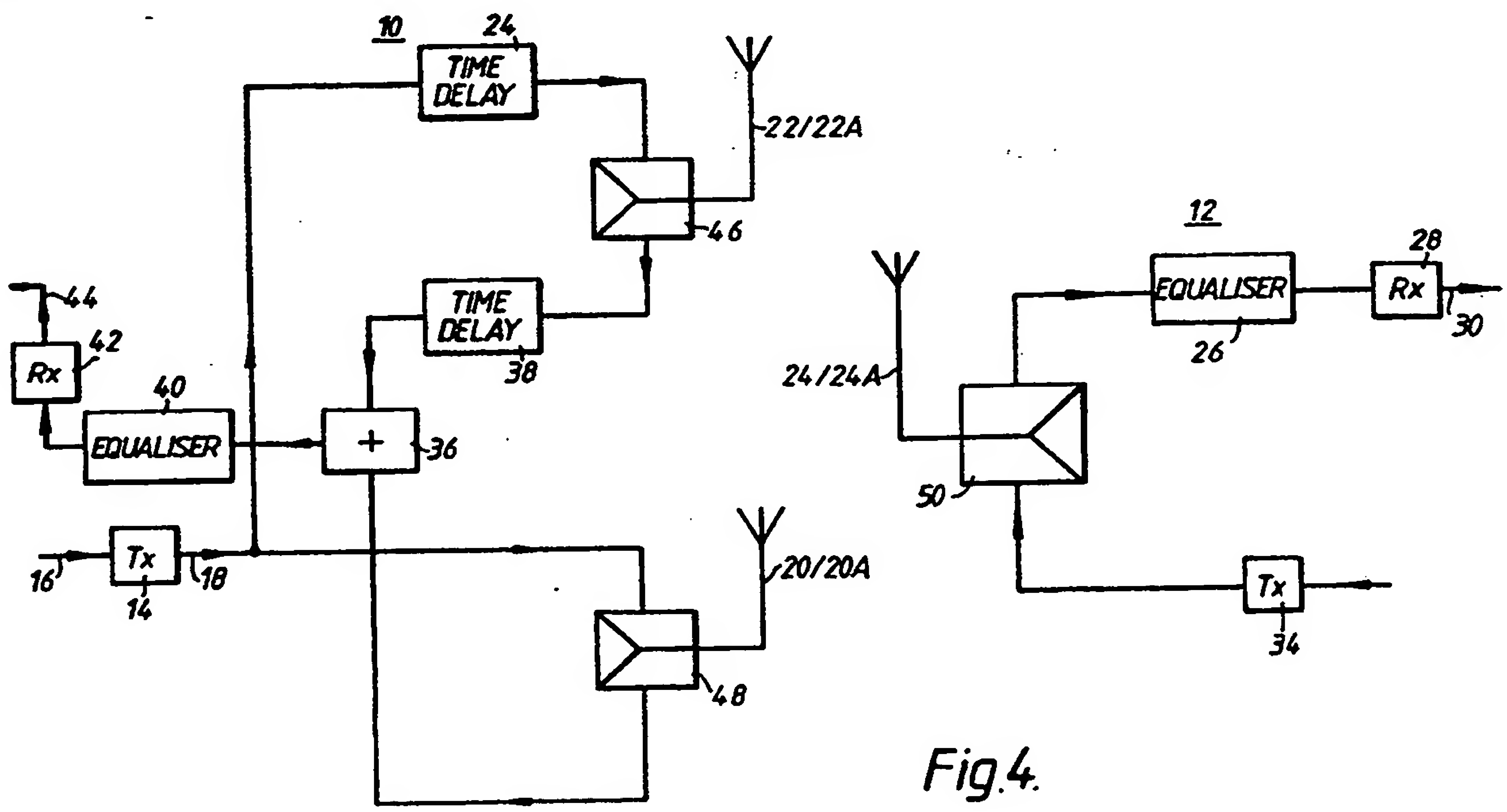

Fig.4.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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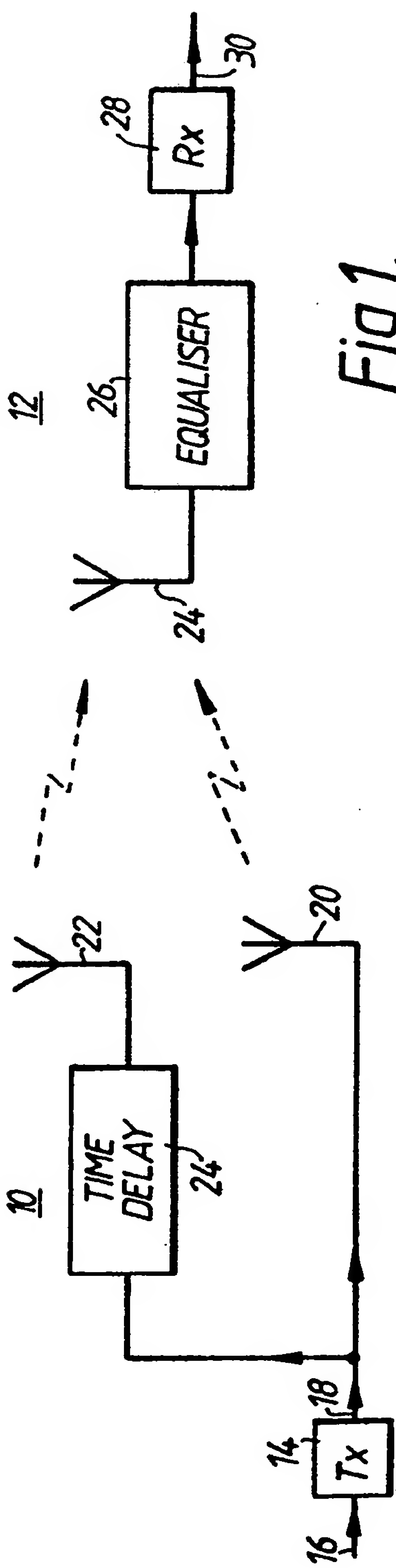

Fig.1.

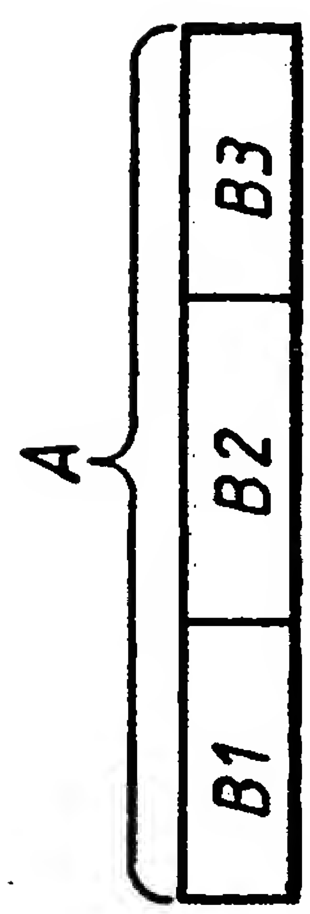

Fig.2.

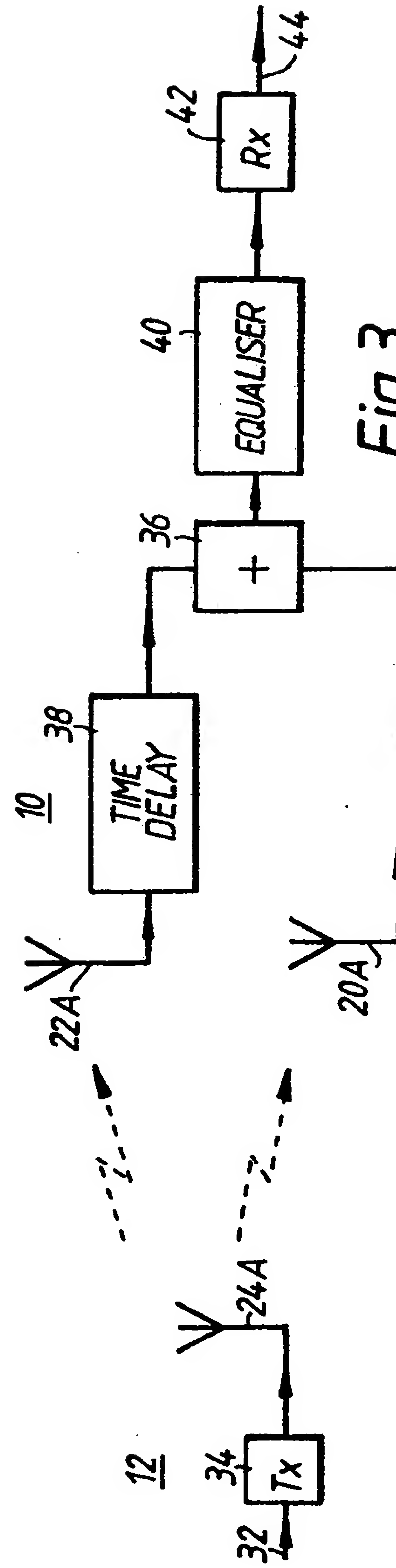

Fig.3.

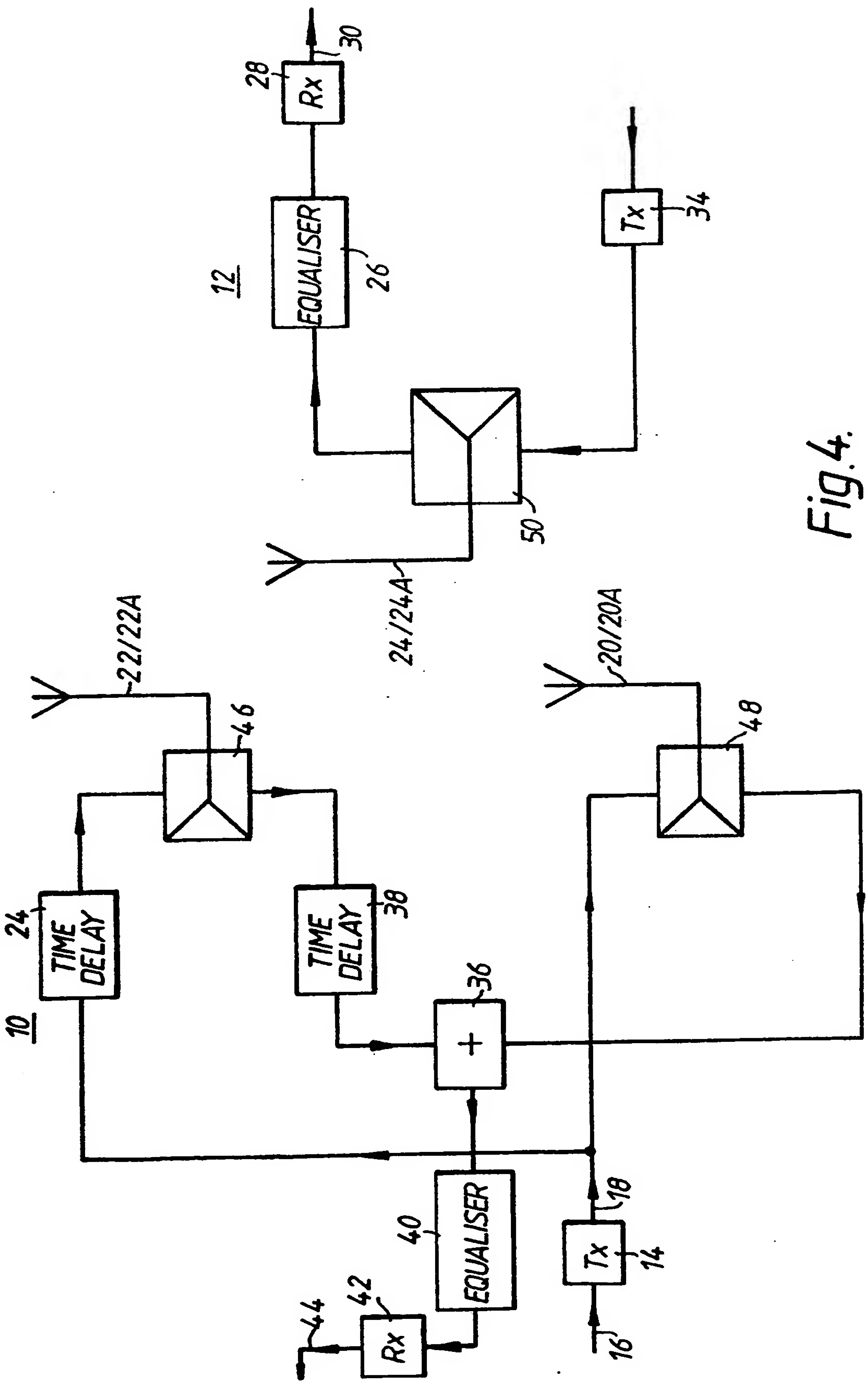
10
12
TIME DELAY
24
TIME DELAY
38
EQUALISER
40
EQUALISER
26
Rx
42
44
Rx
28
30
Tx
14
16
18
Tx
34
36
46
48
50
22/22A
20/20A
24/24A

Fig.4.

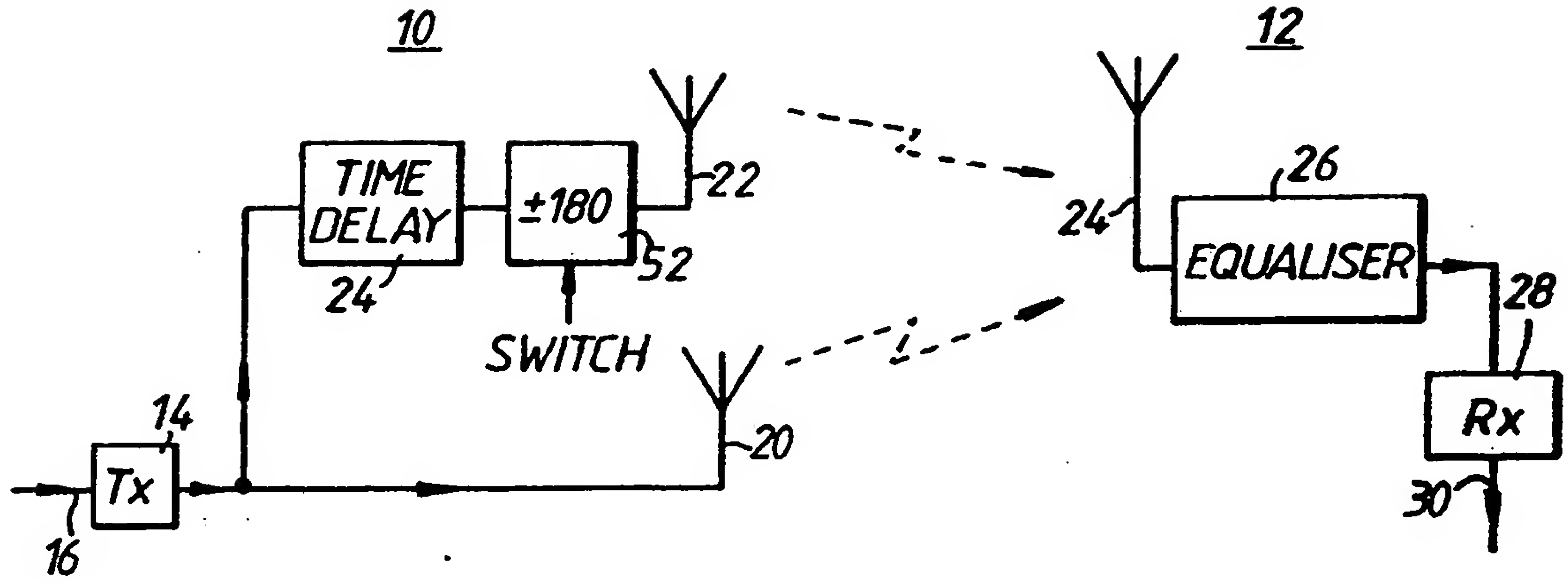
10
12
TIME DELAY
±180
SWITCH
22
52
24
14
Tx
16
20
24
26
EQUALISER
28
Rx
30

Fig.5.

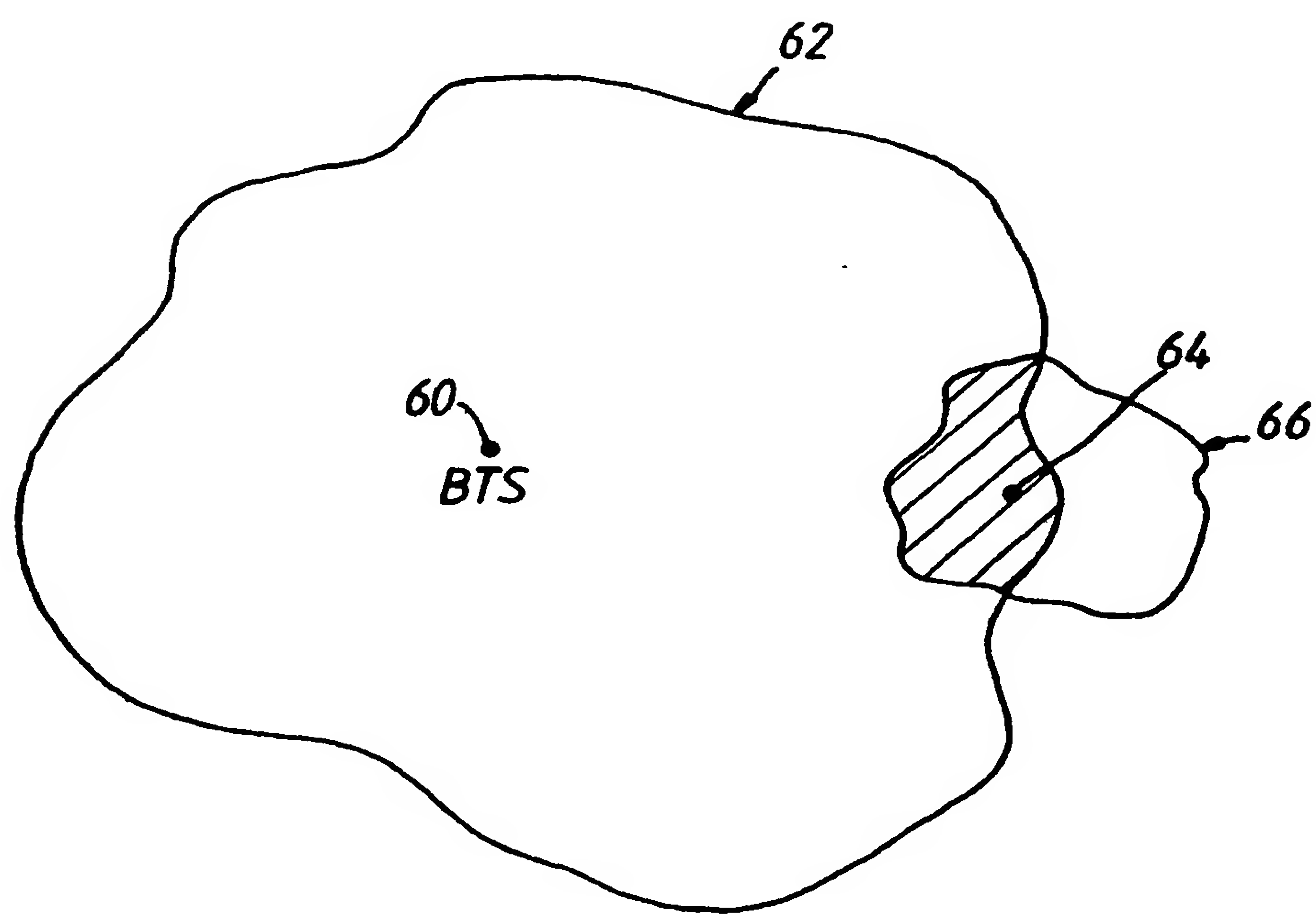
62
60
BTS
64
66

Fig.6.

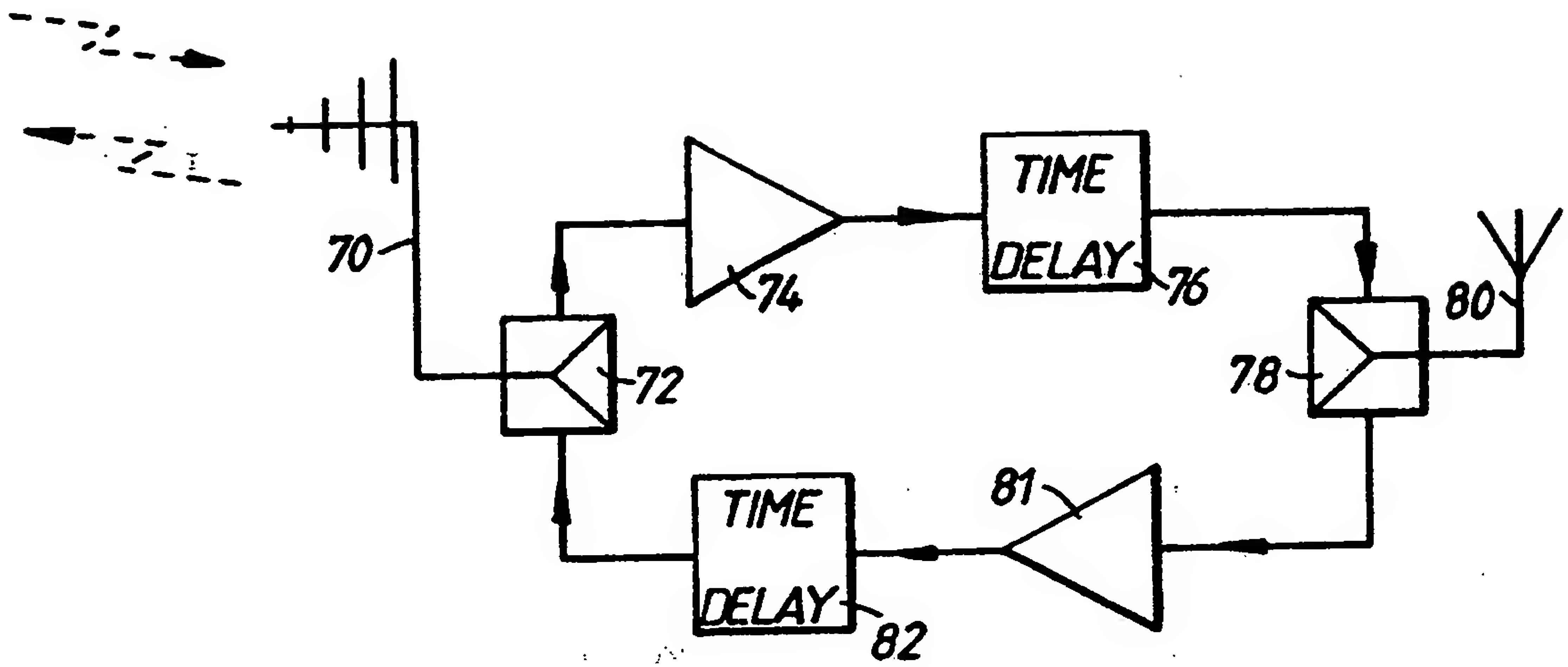
TIME DELAY
TIME DELAY
70
72
74
76
78
80
81
82

Fig.7.

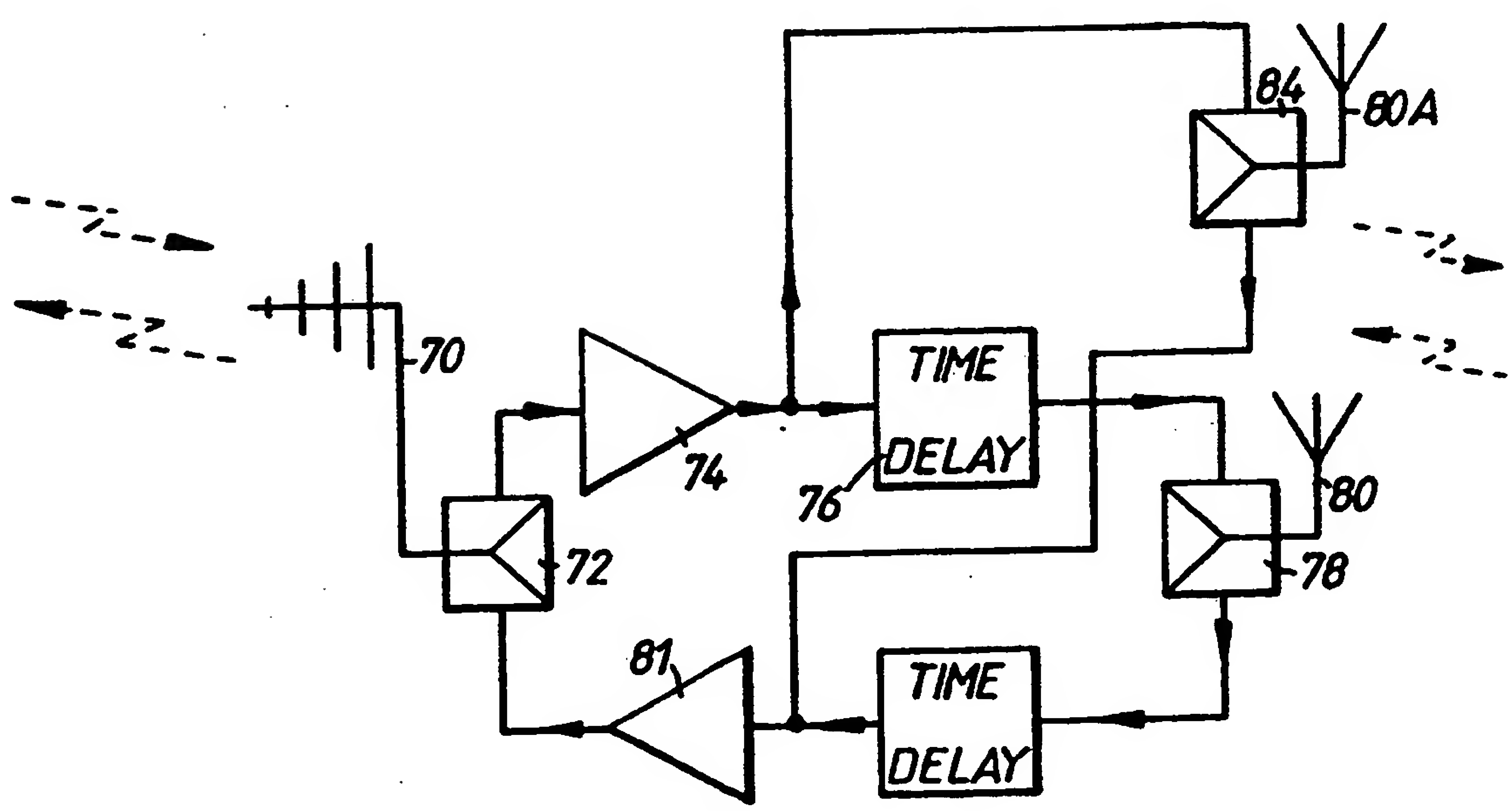
TIME DELAY
TIME DELAY
70
72
74
76
78
80
80A
81
84

Fig.8.

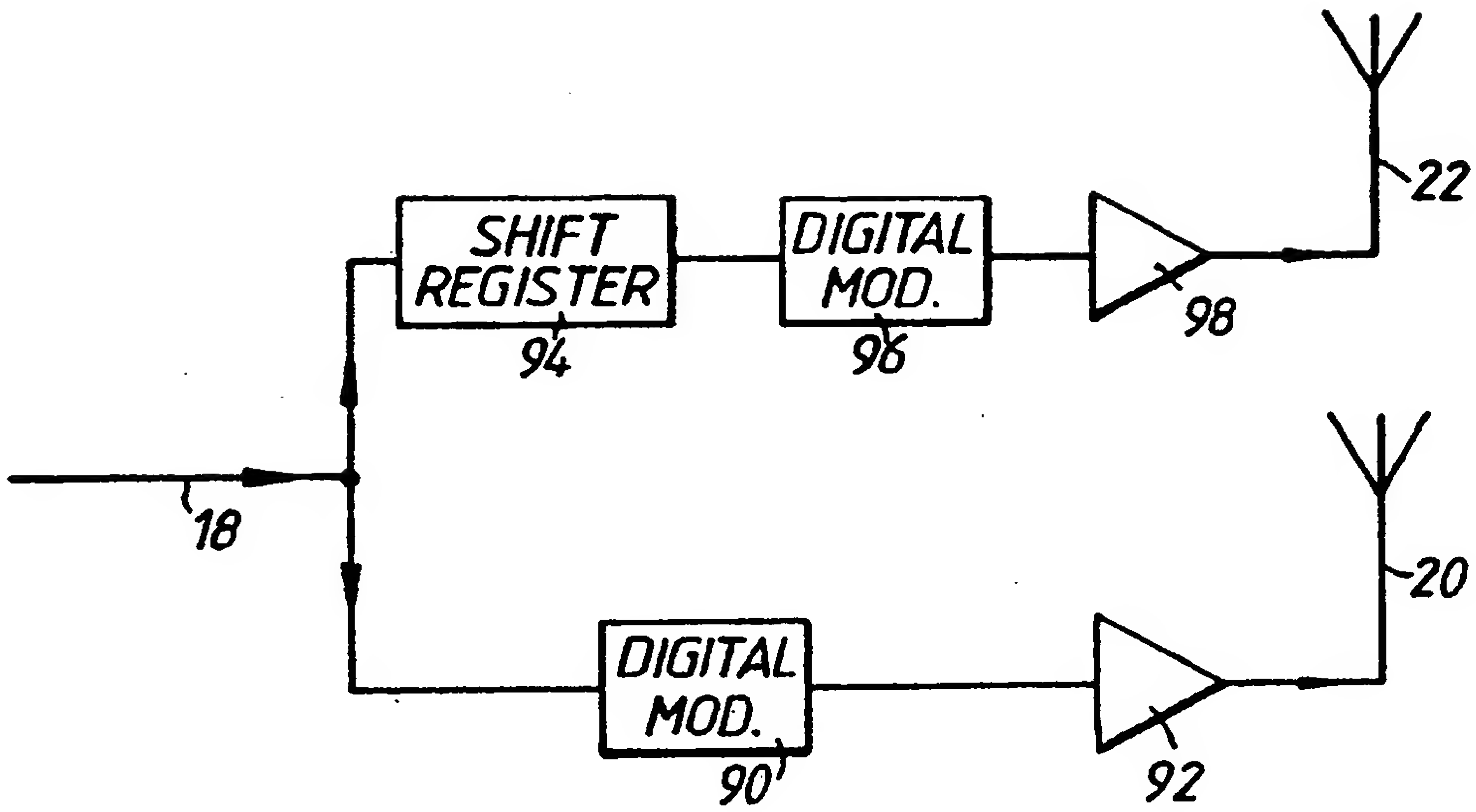
SHIFT REGISTER
94
DIGITAL MOD.
96
98
22
18
DIGITAL MOD.
90
92
20

Fig.9.

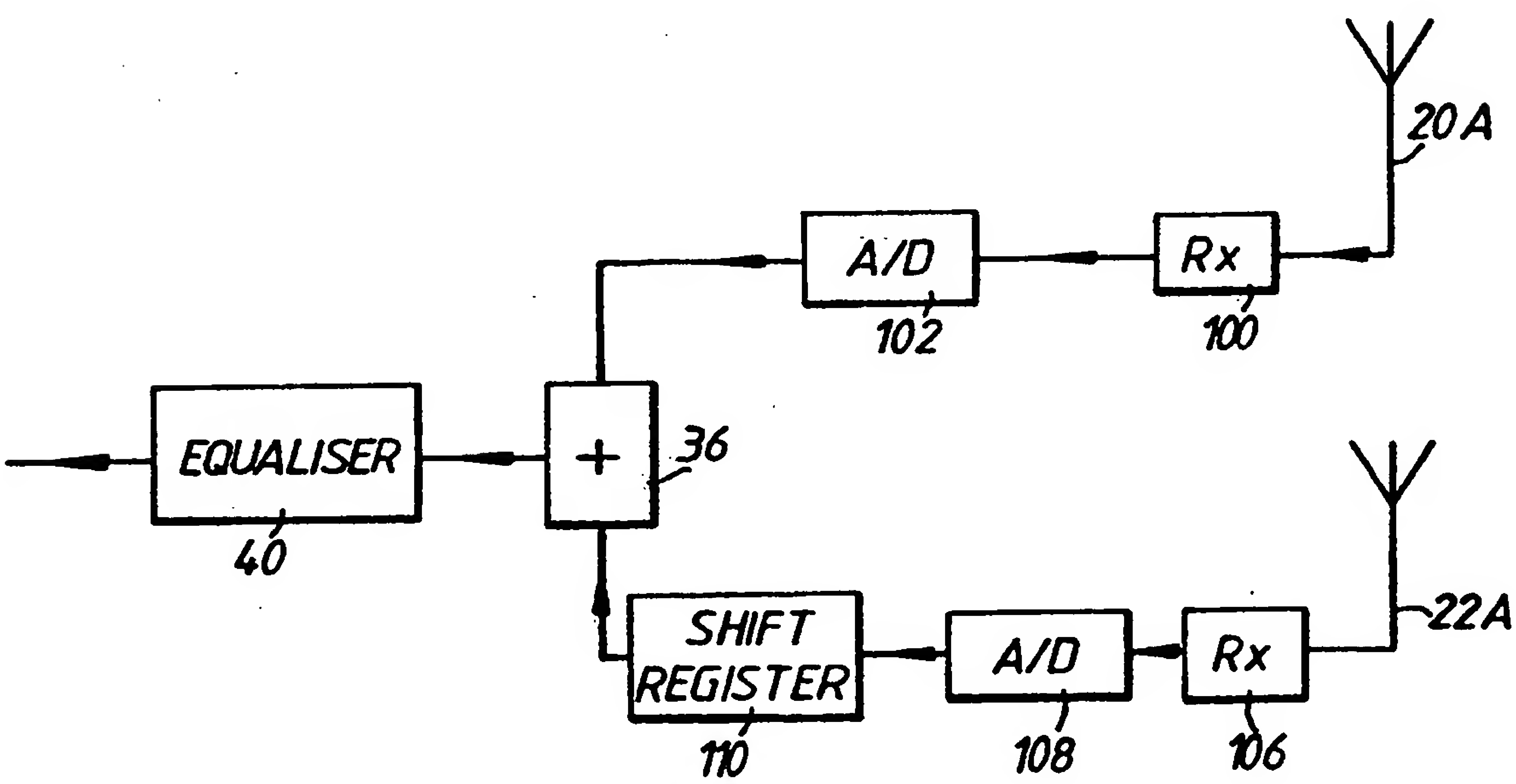
20A
A/D
102
Rx
100
EQUALISER
40
+
36
SHIFT REGISTER
110
A/D
108
Rx
106
22A

Fig.10.

RADIO COMMUNICATION METHOD AND APPARATUS

The invention relates to radio communication methods and apparatus. More particularly, the invention relates to such methods and apparatus applied to a radio communications system involving transmission to and reception from a mobile.

A problem in radio communication systems is multi-path fading. A receiver may receive a radio signal from the transmitter along two or more paths of differing lengths, such as along a direct path and along a path involving reflection. If the relative lengths of the two paths are such that the resultant time delay between the two signals as received by the receiver causes the signals to have such phase difference that they tend to cancel each other out, the resultant signal fading will prevent useful reception. It is known to employ diversity to overcome this problem, diversity involving the use of two or more antennas at the receiver which are mounted at such mutual spacing that the fading characteristics of the two signals are uncorrelated at least to some degree. Therefore, if the signal received by one antenna is substantially attenuated by multi-path fading, it is likely that the signal received by the other antenna will not be significantly affected. Reception therefore

involves selecting the stronger of the two signals at any time.

According to the invention, there is provided a method of providing diversity in a radio communications link, comprising the steps of transmitting radio signals from between two ends of the link via a plurality of signal paths, each signal path being provided between a respective one of a plurality of antennas at one end of the link and a lesser number of antennas at the other end of the link, de-correlating the signals transmitted over the said signal paths, whereby the signal at the receiving end of the communications link comprises the signals as received over the said signal paths and superimposed on each other, and extracting from the superimposed signals the signal corresponding to that originally transmitted.

According to the invention, there is further provided a radio communications link, comprising means for transmitting information between the two ends of the link over a plurality of signal paths therebetween, the signal paths being mutually spatially separated at one end of the link and being co-terminous at the other end thereof, de-correlating means for mutually de-correlating the signals transmitted along the said paths, means for

summing the signals received over the plurality of signal paths, and means for extracting from the summed signals a signal corresponding to the originally transmitted information.

According to the invention, there is still further provided a repeater station for use in a radio communication network, comprising first antenna means for receiving information from an originating station, amplifying means for amplifying the received information, second antenna means for transmitting the amplified information to a receiving station, and time delay means for delaying the signal between the two antenna means whereby to provide de-correlation between the signal transmitted by the second antenna means and the signal transmitted by the originating station.

Apparatus and methods according to the invention and to be described in more detail below are particularly suitable for use in circumstances where it is not practicable to mount two antennas at the receiver with sufficient spacing to achieve diversity which is adequate to overcome multi-path fading. A particular example of a receiver where this situation can arise is the receiver of a mobile such as a hand portable receiver in a cellular radio communication system.

Radio communication apparatus and methods according to the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a block diagram showing the transmitting part of the apparatus in the form of a base transmitting station ("BTS") of a cellular radio system and one of the mobile stations ("MS") of the system;

Figure 2 shows a digital signal transmitted and received in the system of Figs 1 and 2;

Figure 3 is a block diagram of the receiving part of the system shown in Fig. 1;

Figure 4 is a block diagram combining Figs 1 and 3;

Figure 5 shows a modified form of the apparatus of Figure 1 for use in a GSM-type of cellular radio system;

Figure 6 illustrates the use of a repeater station in the system of Figs 1 and 3;

Figure 7 is a block diagram of the repeater station shown in Fig. 6;

Figure 8 is a block diagram of a modified form of the repeater station of Figure 7; and

Figures 9 and 10 are block diagrams showing how time delays can be implemented in the apparatus of Figs. 1 and 3.

For initial ease of explanation, Figure 1 illustrates only the transmission circuitry at a BTS 10 which is a BTS in a cellular radio system in which are situated a number of MS of which one is shown at 12.

The BTS comprises transmission circuitry of known form shown at 14 which receives the incoming signals to be transmitted on a line 16, such as in digital form, and produces a resultant modulated radio signal on a line 18 for transmission. This signal is transmitted to the MS via two antennas 20 and 22. The radio signal on line 18 is passed directly to antenna 20 and is passed to antenna 22 via a time delay unit 24 having a predetermined time delay T.

At the MS 12, there is a single antenna 24 only, which receives the signals transmitted via the two antennas 20 and 22 and feeds them to an equaliser 26, to be described in detail below. The equaliser thus receives the two

transmitted signals superimposed on each other and, in the manner to be explained, extracts a signal corresponding to that originally input at line 16. This signal is fed through normal receiver processing and decoding circuitry shown generally at 28 and output on a line 30.

The delay imposed by the delay unit 24 is sufficient (for example, one or two data bits long) to ensure that the signals transmitted by the two antennas 20 and 22 are uncorrelated with each other. Because the signals respectively transmitted by the two antennas originate from different positions in space, it is unlikely that both of them will fade significantly due to multi-path effects; thus, if one is significantly affected by such effects, the other is likely to be received unaffected. The two transmitted signals cannot interfere with each other to produce a zero resultant because the delay T ensures that the signals are uncorrelated. Therefore, in the general case (that is, assuming that one transmitted signal has not been reduced to zero by multi-path fading), the antenna 24 will receive a pair of signals time-delayed with respect to each other and superimposed one on the other, though with different amplitudes and phases. The equaliser processes this received signal and reconstitutes the originally transmitted data.

The equaliser can take any suitable form. One suitable type of equaliser is a Viterbi equaliser whose principles of operation are well known and will now be briefly described.

It is assumed that the cellular radio communication network is operating in accordance with the GSM protocol.

In the GSM system, data is transmitted in bursts, each burst consisting of two equal length blocks of information, shown at B1 and B3 in Figure 2 and separated by a signal block B2 which consists of a "training sequence" of bits. In the equaliser 26, the received signal A is temporarily stored. The equaliser then inspects the block B2 as received by the antenna 24. The bits as received during the block B2 will consist of the bits as originally transmitted but modified by the impulse response or characteristics of the transmission paths between the two transmitting antennas 20,22 and the receiving antenna 24. Because the pattern of bits as originally transmitted is known, the received block B2 will thus be representative of this impulse response. Thus, if, for example, the training sequence consists of three data bits in the sequential form 010, the signal transmitted as block B2 will represent a bit sequence 010 as modified by the impulse response of the transmission

paths between the BTS and the MS. From this signal, the equaliser can therefore reconstruct the corresponding form which each of the other seven possible three-bit sequences would have when transmitted over the same transmission paths. In this way, therefore, the equaliser is now storing eight signal patterns, each representing the form which a particular one of the eight possible three-bit data sequences would have when received at the receiver over the transmission link having the currently applying impulse response. The equaliser then compares each three-bit sequence in the blocks B1 and B3 with these eight stored patterns so as to determine which of the eight stored bit patterns is closest in form to the three-bit sequence with which it is compared. This process thus enables the latter to be identified and decoded.

In this way, therefore, the equaliser 26 decodes the received signal, consisting of signals received along two transmission paths superimposed upon each other. Multi-path fading is thus avoided - because, as explained, the signals transmitted over the two transmission paths are unlikely both to be subjected to such fading at the same time. All this is achieved without the necessity for using two antennas at the MS. Because of the small physical size of the MS, it is

difficult to space apart two antennas sufficiently to give any useful diversity effect.

It will be apparent that a geographical position for the MS may exist where the signals received along the two transmission paths have both faded substantially to zero. However, the likelihood of this happening is significantly less than the likelihood of one, only, of the signals fading, and thus the probability of successful communication has been increased.

Figure 3 illustrates the circuitry employed in the MS and the BTS during transmission from the MS to the BTS. As shown, the BTS is provided with two spaced antennas 20A and 22A while the MS has a transmitting antenna 24A. Information to be transmitted is fed on a line 32 to encoding and transmitter circuitry 34 in the MS 12 and transmitted by antenna 24A along two transmission paths to the antennas 20A and 22A of the BTS 10. The signals received by the two antennas are fed to an adding circuit 36, the signal from antenna 22A being fed through a time delay circuit 38. As before, multi-path effects may cause the signal received by one of the two antennas to be substantially zero, but the likelihood of the signal received by the other antenna being zero as well is very small. The time delay circuit 38 ensures that the two

received signals are de-correlated and cannot sum to zero. The output from adder 36 is thus the sum of the two signals received. This output is fed to an equaliser 40 which operates in the same manner as described above with reference to Figure 2 so as to decode this signal and produce the originally transmitted data which is processed by further receiving circuitry 42 and output on a line 44.

Figure 4 shows how the circuitry shown in Figures 1 and 3 may be combined using frequency selective diplexers 46,48 and 50, items in Figure 4 corresponding to items in Figures 1 and 3 being correspondingly referenced.

In practice, the transmitted signals between the BTS and the MS will be subject to dispersion because of multi-path effects. Therefore, in order for the introduced time delay (by circuits 24 and 38) to carry out the necessary decorrelation, the amount of the time delay must be greater than this dispersion. If the time delay caused by the dispersion is too great, the equalisers may not operate satisfactorily.

In addition, the amount of time delay needed for correct decorrelation is related to the modulation rate.

In cellular radio networks operating in accordance with the GSM protocol, the BTS transmits a pure sine wave at regular intervals. During such sine wave transmission, the time delay introduced by delay unit 24 (Figs. 1 and 4) will produce no decorrelation between the signals respectively transmitted by the two antennas and the diversity which they are intended to produce will not be achieved. Therefore, the circuitry shown in Figure 1 can be modified as indicated in Figure 5, by the introduction of a phase-changing switch 52. The operation of this switch is synchronised with the time slots during which the BTS produces a pure sine wave. Thus, for example, for every alternate such time slot the switch can be in one of its settings while, during each intervening time slot, the switch can be automatically set in its other setting so as to provide a 180° phase shift. If time delays in the two signal paths are such that the sine waves reaching the MS antenna 24 exactly cancel during the time slots when the switch 52 is in one of its two settings, it is unlikely that such cancellation will occur during the time slots when the switch is in its opposite setting. Therefore, during at least some of the time slots successful diversity is achieved and the risk of multi-path fading reducing the received signal to zero is substantially reduced as before. The successful operation of the GSM protocol does not require that the

pure sine wave be received during every time slot and the fact that the signals received along the two signal paths may cancel out during some of the time slots is therefore not a significant disadvantage.

In a modification, the switch 52 could have more than two phase shift settings.

It will be apparent that Figure 4 could be amended to incorporate switch 52.

The GSM protocol does not involve transmission of pure sine waves from the MS to the BTS and therefore no modification of the MS is required.

Cellular and other radio transmission systems often incorporate repeater stations. Figure 6 shows such a system incorporating a BTS 60 having a coverage indicated diagrammatically at 62. A repeater station RS is shown at 64 having a coverage 66. Where the coverage of the BTS overlaps the coverage of the RS (this overlap is cross-hatched in the Figure), interference may occur. This can be overcome by using circuitry for the RS as shown in Figure 7. As shown in Figure 7, the RS has a receiving and transmitting antenna 70, which is directional and feeds the signal received from the BTS

via a frequency selective diplexer 72 to a transmission path incorporating an amplifier 74, a time delay circuit 76 and thence via a similar diplexer 78 to an omni-directional receiving and transmitting antenna 80 for transmission therefrom. The inclusion of the time delay circuit 76 ensures that the signal transmitted from the BTS and present in the cross-hatched region of Figure 6 cannot interfere with the signal re-transmitted by the RS via antenna 80.

Signals received from an MS by the RS are picked up by antenna 80 and fed via diplexer 78 to an amplifier 81 and thence through another time delay unit 82 and diplexer 72 for re-transmission to the BTS via antenna 70. Time delay 82 prevents interference within the cross-hatched region of Figure 6 between the signal as directly transmitted by the MS and the signal as re-transmitted by the RS.

If a repeater station as shown in Figure 7 is combined with a BTS of the form shown in Figure 4, multi-path fading and mutual signal interference is avoided throughout the total coverage 62 of the BTS. However, multi-path fading can still occur in transmissions between the RS 64 and an MS situated in that part of the coverage 66 of the RS which is outside the coverage 62 of

the BTS. In order to avoid this, the RS can be constructed as shown in Figure 8 in which items corresponding to those in Figure 7 are correspondingly referenced.

As shown, the RS is provided with a second omni-directional transmitting and receiving antenna 80A which is connected via a further frequency selective diplexer 84 to the directional antenna 70 via diplexer 72 and via paths which bypass the time delay circuits 76 and 82. Thus, when the RS is re-transmitting a signal which has been received from the BTS over the two transmission paths from the latter such re-transmission takes place via amplifier 74 and time delay circuit 76 and thence via antenna 80 and, simultaneously, undelayed re-transmission takes place via antenna 82A via amplifier 74 and diplexer 84. Therefore, two separate signal paths to the MS are set up, the signals transmitted being decorrelated by the time delay 76 - in similar fashion to that described above with reference to Figure 1. The received signals would be decoded in the MS in the manner described with reference to Figure 2.

Transmission by the MS to the RS takes place over two signal paths, to antennas 80 and 80A respectively. The signal received by antenna 80 is passed via diplexer 78,

time delay 82 and amplifier 80 to the BTS via directional antenna 70. The signal received by antenna 82A is passed via diplexer 84 directly to amplifier 80 and thence to directional antenna 70 with no time delay. Again, therefore, two signal paths are set up between the MS and the RS to avoid multi-path fading.

When an MS is situated in the cross-hatched region of Figure 6, its equaliser (equaliser 40, see Fig. 3) will have to handle signals delayed by both the time delay 24 (Fig. 1) in the BTS and the time delay 76 in the RS.

The circuitry for the repeaters shown in Figures 7 and 8 does not enable the repeaters to decorrelate the pure sine wave bursts of signal which, as explained above in connection with Figure 5, are transmitted at intervals in a cellular radio network operating according to the GSM protocol. In a manner corresponding to that shown in Figure 5, this problem may be overcome by incorporating a phase shift switch. However whereas, in the BTS circuitry shown in Figure 5, the operation of this switch could be easily synchronised with the time slots in which the pure sine waves are transmitted, such synchronisation is not so easily achieved in the RS and would necessitate special synchronisation arrangements to be made. Instead, however, the switching of the phase shift switch

in the RS could be carried out at random time instants. This would ensure that the required decorrelation took place during at least some of the time slots in which the pure sine wave was being transmitted. Since successful reception of the sine wave by the MS is not required during each such time slot, the possible existence of multi-path fading during some of the time slots would not be a significant problem. Of course, random switching of the phase shift switch would distort the data signals being transmitted. However, the error correction arrangements in the system should be able to handle such distortion. Alternatively, the amount of phase shift and the rate at which it is switched could be chosen such that distortion of the signal is minimised while still achieving the necessary de-correlation.

The time delays required by the circuitry described may be implemented in any suitable way. SAW delay lines can be constructed with the required delay (several micro-seconds) and also have the advantage of being bi-directional. However, in practice the bi-directional property may be difficult to exploit because of the high loss.

A better solution for the BTS is to implement the delay digitally by means of a shift register. Figure 9 shows

Figure 1 modified to show such digital implementation of the delay. Items in Figure 9 corresponding to those in Figure 1 are correspondingly referenced. As shown, the digital signal to be transmitted is fed on line 18 directly to a digital modulator 90 and thence via an amplifier 92 to antenna 20. In addition, the digital signal is fed through shift register 94, providing the delay, and thence to a further digital modulator 96 and an amplifier 98 to antenna 22.

Figure 10 corresponds to Figure 2 and shows the implementation of digital delay methods for the receiving circuitry at the BTS. Items in Figure 10 corresponding to those in Figure 2 are correspondingly referenced. The signal received by antenna 20A is fed through receiving circuitry 100 which de-modulates it and is then passed through an analogue to digital converter 102 and thence to one input of adder 36. The signal received by antenna 22A is de-modulated by receiver circuitry 106 and passed to analogue to digital converter 108 and thence to a shift register 110 providing the necessary delay and to the second input of adder 36. The output of adder 36 feeds equaliser 40.

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CLAIMS

1. A method of providing diversity in a radio communications link, comprising the steps of transmitting radio signals from between two ends of the link via a plurality of signal paths, each signal path being provided between a respective one of a plurality of antennas at one end of the link and a lesser number of antennas at the other end of the link, de-correlating the signals transmitted over the said signal paths, whereby the signal at the receiving end of the communications link comprises the signals as received over the said signal paths and superimposed on each other, and extracting from the superimposed signals the signal corresponding to that originally transmitted.

2. A method according to claim 1, in which the extraction step is carried out by means of an equaliser.

3. A method according to claim 2, in which the equaliser is a Viterbi equaliser.

4. A method according to any preceding claim, in which there are two antennas at the said one end of the link and one antenna at the other end thereof.

5. A method according to claim 4, in which the decorrelating step includes the step of feeding the radio signals to be transmitted from the said one end of the link to one of the antennas there without any time delay and feeding the radio signals to the other antenna at that end via a predetermined time delay.

6. A method according to claim 5, in which the extracting step is carried out by means of an equaliser connected to the single antenna at the other end of the link.

7. A method according to claim 5 or 6, in which the de-correlating step includes the step of applying a predetermined time delay to the signal received at one of the two antennas at the said one end of the link and transmitted from the single antenna at the other end thereof, and applying no time delay to the signal received by the other antenna at the said one end of the link and transmitted by the single antenna at the said other end thereof.

8. A method according to claim 7, in which the extracting step includes the steps of summing the received time-delayed signal with the received signal, non-delayed and feeding the sum of the two signals to an equaliser.

9. A method according to any preceding claim including the step of applying a predetermined phase shift at intervals to the signal transmitted by one, only, of the two antennas at the said one end of the link, whereby to cause at least occasional de-correlation between information in the form of regular-waveform signals transmitted by the two antennas.

10. A radio communications link, comprising means for transmitting information between the two ends of the link over a plurality of signal paths therebetween, the signal paths being mutually spatially separated at one end of the link and being co-terminous at the other end thereof, de-correlating means for mutually de-correlating the signals transmitted along the said paths, means for summing the signals received over the plurality of signal paths, and means for extracting from the summed signals a signal corresponding to the originally transmitted information.

11. A communications link according to claim 10, in which the de-correlating means comprises time delay means applying a predetermined time delay.

12. A link according to claim 11, in which there are two antennas at a first end of the link and a single antenna

at the other end thereof.

13. A link according to claim 12, including means for processing information to be transmitted from the first end of the link to the second end of the link, means connecting the processed information directly to one of the two antennas at the first end, and means for connecting the processed information through the time delay means to the other antenna at the first end.

14. A link according to any one of claims 10 to 13, in which the extracting means comprises an equaliser.

15. A link according to claim 14, in which the equaliser is a Viterbi equaliser.

16. A link according to claim 13 and to claim 14 or 15, in which the equaliser is connected to receive the signals received by the single antenna at the second end.

17. A link according to claim 12, including means for processing information to be transmitted from the second end of the link to the first end of the link, means for feeding the processed information directly to the single antenna at the second end, means directly feeding the signal received by one of the two antennas at the first

end of the link to one input of summing means, and means feeding the signal received by the other antenna at the first end of the link through the said time delay means to the other input of the summing unit, the time delay means applying a predetermined time delay.

18. A link according to claim 17 and to claim 14 or 15, in which the equaliser is connected to the output of the summing means.

19. A link according to any one of claims 12,13 and 16 to 18, in which the said first end of the link is a repeater station, and including antenna means adapted to receive information to be transmitted by the repeater station to the second end of the link and to transmit information received by the repeater station to another location.

20. A repeater station for use in a radio communication network, comprising first antenna means for receiving information from an originating station, amplifying means for amplifying the received information, second antenna means for transmitting the amplified information to a receiving station, and time delay means for delaying the signal between the two antenna means whereby to provide de-correlation between the signal transmitted by the

second antenna means and the signal transmitted by the originating station.

21. A radio communication link, substantially as described with reference to Figure 1 of the accompanying drawings.

22. A radio communication link, substantially as described with reference to Figure 2 of the accompanying drawings.

23. A radio communication link, substantially as described with reference to Figure 4 of the accompanying drawings.

24. A radio communication link, substantially as described with reference to Figure 5 of the accompanying drawings.

25. A repeater station for use in a radio communications link, substantially as described with reference to Figure 7 of the accompanying drawings.

26. A repeater station for use in a radio communications link, substantially as described with reference to Figure 8 of the accompanying drawings.

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